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CONTROL OF BURNING PROCESSES AND ATMOSPHERE POLLUTANTS REMOVAL FROM BURNING INSTALLATIONS IN AN ELECTRIC FIELDS

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ABSTRACT
An apparatus, consisting of a Seitan 20 gas burner with a fuel flow rate 20 m^3N/h, supplied with a system of Kanthal electrodes and an adjustable source of a high voltage, was investigated. It was found that an increase of voltage up to 12 kV, and current up to 32 μA, respectively, results in the evident improvement of the burning process: increasing of flame temperature from 1100 up to 1190^oC, decreasing of CO percentage from 1.2 up to 0.012 %, reducing of the fuel consumption about 5%. A new technology of nitrogen and sulphur oxides removal in the installations for burning of organic fuels under action of pulsed corona discharge and alternating electric field, is proposed.
Keywords: control of burning, SO_2 and NO_X removal, electric field

1. ENHANCEMENT AND CONTROL OF BURNING PROCESS IN AN ELECTRIC FIELD

1.1. Introduction
Although an interaction of the external electric field with the flame was known as early as XVII century, theories accounting for this phenomenon were developed only recently [1].
Present investigation of the burning process is aimed at the increase of efficiency, that is decreasing of the specific fuel consumption, increasing of the flame temperature, significant reducing of CO content in the exhaust gases.

1.2. Experimental apparatus and technique of measurements
The experimental apparatus consisted of a Seitan 20 gas burner with a fuel flow rate 20 m^3_N/h, a high voltage source of alternative current, and a combustion chamber with embedded Kanthal electrodes connected to the source of a high voltage.
The experimental apparatus was mounted on a specialized testing bench of Bucharest Metallurgic Research Institute, ROMANIA.
A controllable difference of potentials in the range of 0-12 *kV* was applied to an interelectrode gap with the width of 50 *mm*. At voltages 0, 3, 5, 7, 9, and 12 *kV* and fuel flow rates of 7, 12, 16, 18, 20,

and 30 m^3_N /*h* were measured the pressure of fuel gases, temperature and composition of exhaust gases, transfer current density in the flame.

The following equipment was used for measurements: Fluke digital multimeter with the range of currents 0-10 *A*, grade of fit 1 μA/ 1.2 % (for measuring of current in the primary circuit of the high voltage source); voltmeter with the range 0-500 *V*, grade of fit 1.5 (for measuring of voltage in the primary circuit of the high voltage source); microamperemeter with the measuring probe with the range 0-200 μA, grade of fit 1.5 (for measuring of the current transferred by the ions in the flame and finding the regions with the maximum electric conductivity of the flame); cathode oscilloscope with the ranges 0-20 *kV*, 0-20 A, 0-60 *Hz*, grade of fit 0.5 (for measuring of voltage in the secondary circuit of the high voltage source and observance of the shape of high voltage tension); thermocouple Pt-Rd 13, 0-1800 ^oC, ± 6.5 ^oC (for measuring of the flame temperature); Kent type diaphragm, 0-25 m^3_N /*h*, ± 2 % (for measuring of gas fuel flow rate); U-shape manometer, 0-1000 *mm* H_2O, ± 0.5 *mm* H_2O (for measuring of gas fuel static pressure); TESTO-350 gas analyzer with the electrochemical cells, 0-20000 *ppm* and ± 20 *ppm* (CO), 0-21 % and 0.2 % (O_2), 0-20000 *ppm* and ± 20 *ppm* (NO_x) (for measuring of content of CO, O_2, and NO_x in the exhaust gases); INFRALYT 2020 infrared gas analyzer, 0-20 %, 0.2 % (for measuring of CO_2 content in the exhaust gases).

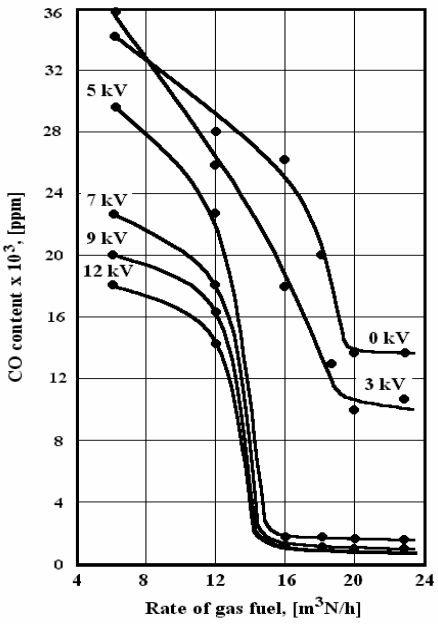

Fig.1. Variation of CO content in the exhaust gases in dependence of the voltage on the electrodes and of fuel flow rate

1.3. Experimental results and analysis

The experimental results obtained at variation of the flow rate of fuel gases both in the absence of the electric field and at various voltages are shown in the Figs. 1-4.

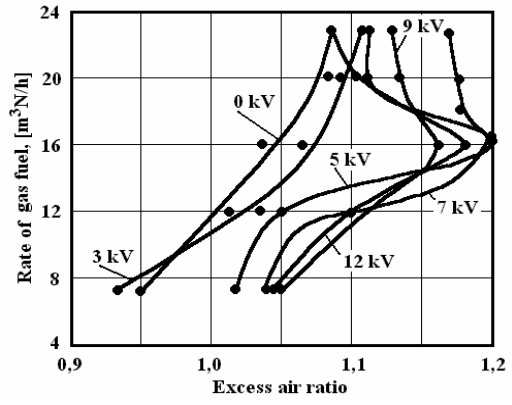

Fig. 2. Variation of excess air ratio in dependence of the voltage on the electrodes and of fuel flow rate

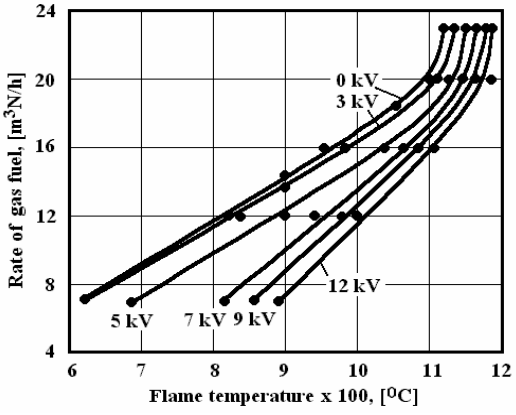

Fig.3. Variation of the flame temperature in dependence of the voltage on the electrodes and of fuel flow rate

Analysis of these data shows that electric field doesn't influence significantly on the pressure-flow rate characteristic of the fuel. The maximum value of the current in the flame at the upper value of high voltage (12 *kV*) is 32 μA. Current-voltage characteristic is in the area of Ohm low applicability. In the absence of the external electric field an existence of intrinsic flame current of the order of 0.4 μA was revealed. In the absence of the electric field the CO concentration in the exhaust gases exceeds 1.2 % (12000 *ppm*). It means a low burning efficiency and exceeding of the maximum permissible concentration which is regulated by the ecological standard in force (170 mg/m^3_N). At the voltages on the electrodes exceeding 7 *kV* and fuel flow rates 15-25 m^3_N /*h*, the CO content in the

exhaust gases decreases up to 0.01-0.03 % (Fig. 1). At the voltage of 12 *kV* and the nominal flow rate of fuel gases for this burner CO content is equal to 16 *ppm* or 136.6 mg/m^3_N. At the flow rates less than 15 m^3_N/h and voltages in the investigated ranges it was impossible to decrease the CO content till the permissible level that can be accounted for the design of the burner. The air necessary for burning is injected by the fuel gases that makes it impossible to maintain an optimum value of excess air ratio at the low flow rates (Fig. 2).

An increase in voltage on the high voltage electrodes increases the flame temperature that can be accounted for a shift of heat-chemical reaction in the area of primary formation of CO_2 molecules instead of CO ones (Fig. 3).

As soon as this type of burner doesn't allow for obtaining of high temperatures at which NO_x is formed, the influence of the electric field is in the range of accuracy for these experiments and NO_x formation depends mainly on gas fuel flow rate (Fig. 4). In the range of the flame temperatures under consideration NO_x content doesn't exceed the permissible value (350 *ppm* or 450 mg/m^3_N).

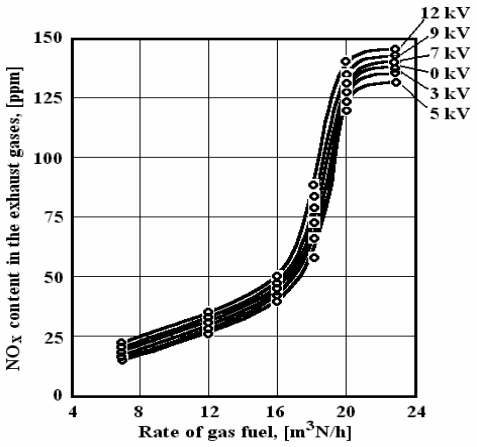

Fig. 4. Variation of NO_X content in the exhaust gases in dependence of the voltage on the electrodes and of fuel flow rate

2. ATMOSPHERE POLLUTANTS REMOVAL FROM BURNING INSTALLATIONS IN AN ELECTRIC FIELDS

The technologies of NO_x and SO_2 simultaneous removal from exhaust gases are based in the following conceptual scheme: the exhaust gases get energy necessary for ionization and formation of active radicals of O, OH, HO_2, which oxidize molecules of NO_x and SO_2, being further transformed in corresponding acids – sulphuric through the reaction of hydrolyze and neutralization by means of introduction of ammonia in gas, and getting of sulphate and nitrate of ammonia in the fine particulate form, which are seized by electro-filter. These technologies are distinguished by the mode, in which the exhaust gases receive the energy necessary for ionization.

The old technologies, in which the exhaust gases were ionized by beams of accelerated electrons [2], were replaced by the new based on the treatment of the exhaust gases with "cold plasma" induced in the corona discharge system with electrodes [3,4], in the microwaves system without electrodes [5] or in combined fields of corona discharge and microwaves [6].

In the case of electrical discharges, energy for ionization of the exhaust gases is getting due to application of high voltage (negative direct, pulsing or alternating positive) to the system, which consist of group of filament electrodes, placed in the center of a gas channel formed from two parallel metallic plates connected to the ground [3,4]. If the electric field intensity is high enough that accelerated electrons could ionize the exhaust gases molecules, the presence of the free electrons in this region is sufficient for developing of corona discharge and formation of the other electrons, positive and negative ions, active radicals (excited atoms and molecules) required for the process.

The italian firm ENEL produced the installation for experimental research of NO_x-SO_x removal by combined using of pulsed corona discharge with using of three reactors [3]. For the supply of the electrodes it was using the high voltage generator with value of voltage in pulsed regime about 80 *kV* that corresponds to current density through the ground electrode on the level of 30 A/m^2. The duration of the impulse was from 1 to 2 μs with rise of impulse 20 *ns*. The frequency of the impulses repetition was up to 300 *impulses/s*.

The efficiency of NO_x and SO_2 removal can be increased by means of the application of an alternating electric field to ionized by pulsed corona discharge exhaust gases [4]. The effective intensity of alternating field is in the range 5-30 *kV/cm* and the frequency f, $[Hz]$, is determined by the condition:

$$f = (1{,}10...1{,}25)\frac{k_{\max} \cdot \overline{E}}{l}, \qquad (1)$$

were k_{max} is the maximum magnitude of the mobility of the ions, [$m^2/(V\,s)$]; $\bar{E}$ – the effective intensity of the alternating electric field, [V/m]; l – the distance between electrodes, [m].
The ionized particles are involved in the oscillating movement in the alternating field that increases the probability of the collisions between them and the neutral molecules, intensifying the reactions of NO_x and SO_2 conversion.
The tests carried out with using of new process have confirmed the possibility of the efficiency improvement at the nitrogen oxides removal up to 90% and the sulphur oxides removal up to 95…98% (Tables 1,2).

Table 1. Influence of alternating electric field effective intensity $\bar{E}$ on the efficiency of NO_x and SO_2 removal from exhaust gases

$\bar{E}$, kV/cm	0	4	5	10	20	30	35
f, kHz	0	0,79	1,0	2,0	4,0	6,0	7,0
NO_x removal, %	50	52	59	81	86	90	Electrical break-down in exhaust gases
SO_x removal, %	75	76	80	90	93	95	

The efficiency of NO_x and SO_x removal is higher in the case of the presence of alternating electric field with the intensity in the range 5-30 *kV/cm* than in the case of $DeNO_x$-$DeSO_x$ technology [3] (Table 1, column $\bar{E}$ =0, f=0), but the variation of the field frequency, regarding reference value of f = 4 *kHz*, determined from Eq.(1), leads to the diminution of the removal efficiency. For the frequency f < 4 *kHz* this decrease is explained by the fact that a part of the ions are neutralized on the wall of the tube connected to ground and does not participate in the electrochemical reactions. In the case, when f > 4 *kHz*, the oscillating movement of the ions in the alternating electric field takes place in restricted space that decreases the probability of the collisions between ions and between ions and the neutral molecules and as a consequence, the efficiency of the nitrogen and sulphur oxides removal.

Table 2. Influence of the frequency of alternating electric field on the efficiency of NO_x and SO_2 removal from exhaust gases

$\bar{E}$, kV/cm	2,0	3,0	3,6	4,0	6,0	8,0
f, kHz	20	20	20	20	20	20
NO_x removal, %	23	35	48	86	64	57
SO_x removal, %	31	56	70	93	86	81

The technologies of the nitrogen and sulphur oxides removal by electric field have such advantages as reduced consumption of ammonia, small losses of pressure through installation and obtaining of some products which can be possibly used as fertilizers.

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